

# Quantifying soil organic carbon in forage-based cow–calf congregation-grazing zone interface

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**Abstract** Recent concerns about global warming due to accumulations of atmospheric CO<sub>2</sub> have encouraged the achievement of better understanding of the roles of animal agriculture in mitigating CO<sub>2</sub> emissions. Grazing can accelerate and alter the timing of nutrient transfers, and increase the amount of nutrients cycled from plant to soil. Our reason for conducting this study is to test whether cattle congregation sites (CCS) typical on most Florida ranches, such as mineral feeders (MF), water troughs (WT), and shaded areas (SA) have higher soil organic carbon (SOC) than in other locations of pasture under forage-based system. Baseline soil samples around the congregations zones (MF, WT, and SA) and grazing zones in established (>10 year), grazed cow–calf pastures were collected in the spring and fall of 2003, 2004, and 2005, respectively. Soil samples were collected from two soil depths (0–20 and 20–40 cm) at different locations around the CCS following a radial (every 90 degrees: N, S, E, and W) sampling pattern at 0.9, 1.7, 3.3, 6.7, 13.3, 26.7, and 53.3 m away from the approximate center of MF, WT, and SA. The levels of SOC varied significantly

with CCS ( $P \leq 0.001$ ), distance away from the center of the CCS ( $P \leq 0.05$ ), sampling depth ( $P \leq 0.001$ ), sampling year ( $P \leq 0.001$ ) and the interaction of CCS and soil depth ( $P \leq 0.001$ ). Sampling orientations did not significantly affect the levels of SOC. The SA sites had the highest level of SOC of 3.58 g kg<sup>-1</sup>, followed by WT sites (3.47 g kg<sup>-1</sup>) and MF sites (2.98 g kg<sup>-1</sup>). Results of our study did not support our hypothesis that cattle congregation sites typical on most ranches, such as MF, WT and SA, may have higher concentrations of SOC. The levels of SOC (averaged across CCS) within the congregation zone (3.42 g kg<sup>-1</sup>) were not significantly ( $P \leq 0.05$ ) different from the concentrations of SOC at the grazing zone (3.16 g kg<sup>-1</sup>).

**Keywords** Soil carbon · Cow–calf · Congregation zones · Bahiagrass · Nutrient cycling · Pastures · Carbon sequestration · Grazing

## Introduction

Widespread concerns about increasing atmospheric CO<sub>2</sub> and global changes have increased the need for data and information on the global carbon (C) cycle. The forests of the world have been the focus of most of the research on terrestrial C sequestration while other parts of the agro-ecological systems like pastures or grasslands have received less research

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attention (LeCain et al. 2002). Grasslands comprise approximately 40% of the world's terrestrial surface and are a significant component of the global C cycle (LeCain et al. 2002). Several facets of agricultural land management and land use changes have been examined for their potentials to increase soil C stocks (Paustian et al. 1997; Bruce et al. 1999; Lal et al. 1999). Lal et al. (1998, 1999) estimated that potential soil C sequestration from improved management of US cropland was 75–208 Tg C (Teragrams =  $10^{12}$  g). However, data used by these researchers cannot be readily extrapolated to changes in all agro-ecosystem concentrations because soils, climate and management regimes vary locally and regionally (Gebhart et al. 1994; Ma et al. 2000).

Other researchers argued that land use and land management are key drivers of global C dynamics (Schimel 1995; Houghton et al. 1999), but the roles of pastures or grasslands management have only recently received attention as substantial potential C sink (Follett et al. 2000; Conant et al. 2001). Various management practices such as fertilization, use of improved grass and legume species, and improved grazing management all lead to C sequestration in grasslands (Conant et al. 2001). In many ecosystems, grazing reduces aboveground net primary productivity, but there are cases where grazing actually increases aboveground net primary productivity (Sims and Singh 1978; Milchunas and Lauenroth 1993).

The rate at which soil C accumulates in terrestrial beef agro-ecosystems is uncertain, as are the mechanisms responsible for the current C sink. Understanding cattle movement in pastures is critical to understanding their impact on agro-ecosystems. Movement of free-ranging cattle varies due to spatial arrangement of forage resources within pastures (Senft et al. 1985), proximity of water (Holechek 1988; Ganskopp 2001), mineral feeders (Martin and Ward 1973), and shades to grazing sites. Temperate *Bos taurus* British breeds (Angus and Herford) grazed less during the day than tropically adapted *Bos taurus* Senepol cows, but compensated for reduced grazing activity during the hotter parts of the day by increasing grazing at night (Hammond and Olson 1994; Bowers et al. 1995).

Grazing animals can have dominant effects on the movement and utilization of nutrients through the soil and plant systems, and thus on the fertility and C dynamics of pasture soils (Haynes 1981; Haynes and

Williams 1993; Sigua and Tweedale 2003) and on soil physical properties. Grazing can accelerate and alter the timing of nutrient transfers and increase the amount of nutrients cycled from plant to soils (Klemmedson and Tiedemann 1995). Franzluebbers et al. (2000) reported that over long periods, the position of shade and water resources for grazing cattle could influence the spatial distribution of soil biochemical properties including SOC, nitrogen, particulate organic C and nitrogen, microbial biomass, and net nitrogen mineralization.

We hypothesized that cattle congregation sites are more nutrient-rich and may contribute more nutrients to surface and groundwater supply and may have higher concentrations of SOC than in other pasture locations. Grazing animals congregate close to the shade and watering areas during the warmer periods of the day (Mathews et al. 1994; Mathews et al. 1999). White et al. (2001) claimed that there was a correlation between time spent in a particular area and the number of excretions and this behavior could lead to an increase in the concentrations of soil nutrients and soil C close to shade and water. Lack of a clear relationship between grazing practices and SOC has been attributed to inherent soil variations, depth of soil sampling, and insufficient evaluation of C distributions within pasture system (Manley et al. 1995; Schuman et al. 1999). The effects of animal congregation management that control C cycling and distribution have not been sufficiently evaluated. Current literatures suggest no clear general relationships between grazing management and C sequestration. Some studies have reported no effect of grazing on SOC (Milchunas and Lauenroth 1993; Dormaar et al. 1977), while several studies (Derner et al. 1997; Schuman et al. 1999; Weinhold et al. 2001) determined increases in SOC due to grazing. Our reason for conducting this study is to determine whether cattle congregation zone typical on most ranches, such as mineral feeders, water troughs, and shade areas may have higher SOC than in other pasture locations (e.g. grazing zone).

## Materials and methods

### Study sites and description

The Subtropical Agricultural Research Station (STARS) is a cooperative research unit of the United

States Department of Agriculture (USDA)-Agricultural Research Service (ARS) and the University of Florida and is located seven miles north of Brooksville, FL (28.60–28.63°N; 82.36–82.38°W). The station has three major pasture units with combined total area of about 1,538 ha with 1,295 ha in permanent pastures. Cattle used for nutritional, reproductive, and genetic research on the station include about 500 breeding females with a total inventory of about 1,000 head of cows, calves, and bulls. Most of the soils at STARS can be described as well-drained, Candler fine sand, uncoated hyperthermic family of the Typic Quartzipsaments. Forage production potential of the soils in the station is generally low to medium; the main limitation being droughtiness.

Table 1 shows some of the selected properties of surface (0–25 cm) soils in the pasture units of STARS. The average annual precipitation in the station is about 1,262 mm with approximately half of this amount occurring during mid-June through mid-September. The lowest average temperature of 14°C occurs during January, but frosts are frequent during the winter months. The highest average temperature occurs during August although highs in the mid-30°C range occur regularly from May through September.

**Table 1** Selected properties of surface soil (0–25 cm) averaged within respective beef pasture field of STARS, Brooksville, FL

Property	Main station (28.60–28.63°N; 82.36–82.38°W)	Turnley unit (28.58–28.62°N; 82.26–82.29°W)	Average
Texture (g kg <sup>-1</sup> )			
Sand	750	825	787.5
Silt	200	125	162.5
Clay	50	50	50.0
Bulk density (g cm <sup>-3</sup> )	1.45	1.46	1.45
pH in water	6.27	6.38	6.32
Calcium (mg kg <sup>-1</sup> )	874.1	1145.3	602.9
Magnesium (mg kg <sup>-1</sup> )	93.4	97.9	88.8
Potassium (mg kg <sup>-1</sup> )	63.4	79.0	48.0
SOC (g kg <sup>-1</sup> )	3.4	3.5	3.45

Cattle production at the station is forage-based with the tropical grass, bahiagrass (BG, *Paspalum notatum*, Flügge), the predominant forage species (1,295 ha). Most of the BG pastures have been established for over 30 years. The other major forage species (255 ha) is rhizoma peanuts (RP, *Arachis glabrata*, Benth), a tropical legume with forage quality similar to alfalfa (*Medicago sativa*). Rhizoma peanut pastures are not pure stands of legume, but are mixtures with BG and bermudagrass (*Cynodon dactylon*). Most of the rhizoma peanuts stands were planted between 1980 and 1990.

#### Pasture management and fertilization

Throughout the years, fertility and management practices at the station have been based on University of Florida's recommendations as described by Chambliss (1999). In general, all pastures were grazed during the spring of the year when normal drought conditions limit forage production. After the start of summer rainy season, pastures that were to be hayed were dropped out of the grazing cycle (usually starting in July) and forage growth allowed to accumulate for hay production. Prior to about 1988, pasture fields with BG were fertilized in the spring with 90 kg N ha<sup>-1</sup> and 45 kg K<sub>2</sub>O ha<sup>-1</sup>. At the beginning of 1990, all BG pasture fields received a reduced rate of N fertilization (76.5 kg N ha<sup>-1</sup>). Rhizoma peanuts were fertilized annually with P (38.5 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) and K (67.5 kg K<sub>2</sub>O ha<sup>-1</sup>) since establishment and were managed for grazing in the spring until July followed by haying in late summer/early fall.

Historically, grazing cattle were rotated among pastures to allow rest periods of 2–4 week based on herbage mass. The timing of movement for rotationally grazed cattle was determined by the herd manager's perception of forage availability based on plant height and not based on pasture measurement. Starting in 2000, cattle were rotated on a 3 days grazing interval with 24 days of rest between pastures. For this study, the average number of grazing cattle was about 2.91 animal unit (450 kg cow) ha<sup>-1</sup> and grazing days of about 5.46 on a monthly basis (Table 2). Table 2 also shows the average density of congregation zones (MF, WT and SA), stocking density and number of grazing days per unit pasture area.

**Table 2** Average density of congregation zone (MF-mineral feeders, WT-water troughs, SA-shaded areas/trees), stocking density and number of grazing days per unit pasture area

Pasture unit	Average pasture area (ha)	Average density of congregation zone per unit pasture area (%)			Average stocking density (AU per unit pasture area (AU <sup>†</sup> /ha))	Average number of grazing days per pasture (days)
		MF	WT	SA		
Land use ( $n = 3$ )	15.4	0.34	0.34	0.34	2.85	5.46
Main station ( $n = 3$ )	12.1	0.44	0.44	0.34	3.63	5.46
Turnley ( $n = 3$ )	19.4	0.27	0.27	0.27	2.26	5.46
Mean	15.6	0.35	0.35	0.35	2.91	5.46

<sup>†</sup> AU Animal Unit (450 kg cow)

### Soil sampling, sample preparation and analyses

Soil samples around the congregation sites (MF,  $n = 3$ ; WT,  $n = 3$ ; and SA,  $n = 3$ ) in established (>10 year), grazed pastures were collected in the spring and fall of 2003, 2004, and 2005, respectively. Soil samples were collected from two soil depths (0–20 cm and 20–40 cm) at different locations around the CCS following a radial (every 90 degrees) sampling pattern at 0.9, 1.7, 3.3, 6.7, 13.3, 26.7, and 53.3 m from the approximate center of each MF, WT and SA. For the purpose of this study, sampling sites at 0.9, 1.7 and 3.3 m from the center of CCS were referred to as the “congregation zone” while sites located at 13.3, 26.7 and 53.3 m away from the center of congregation structures were referred to as the “grazing zone”. Bulk density was also assessed on separate soil cores (Blake and Hartge 1986).

Soil samples were air-dried and passed through a 2 mm mesh sieve prior to analysis of SOC. Analyses of soils taken in 2003 and 2004 were conducted at the Subtropical Agricultural Research Station in Brooksville, FL following the dry-ash or the “loss-on-ignition” (LOI) method, while soil samples taken in the fall of 2005 were analyzed using dry combustion method (Elementar CNS Analyzer). The LOI method is a procedure in which samples are dried at 105°C and then ashed at 600°C. The loss in weight between 105 and 600°C constitutes the soil organic matter content. The LOI results compare favorably with those obtained by dichromate wet-oxidation and by Carbon Analyzers (Gallardo and Saavedra 1987; Lowther et al. 1990; Schulte et al. 1991).

### Statistical analysis

Data were analyzed using the PROC MIXED procedures (SAS 2000). The model included cattle congregation sites (CCS), sampling position (SP), distance away from the center of congregation sites (DC), soil depth (SD), and their interactions as fixed effects and replicate as random effect. The pooled data (2003, 2004 and 2005) were tested initially for normality (SAS 2000). Where the *F*-test indicated a significant ( $P \leq 0.05$ ) effect, means were separated following the procedures of Duncan Multiple Range Test.

### Results and discussion

There was a cattle congregation sites  $\times$  soil depth interaction ( $P \leq 0.001$ ) on the concentration of SOC (Table 3). Soil C in these pastures also varied significantly among cattle congregation sites ( $P \leq 0.001$ ), distance away from the center of CCS ( $P \leq 0.05$ ), sampling position ( $P \leq 0.01$ ), time of sampling ( $P \leq 0.001$ ), and sampling depth ( $P \leq 0.001$ ). The effect of distance away from the congregation sites on SOC is shown in Fig. 1. The concentration of SOC in MF was not affected by the distance away from the center of CCS. However, concentrations of SOC in SA and WT significantly ( $P \leq 0.05$ ) declined with distance away from the center of CCS (Fig. 1). Average concentration of SOC within the grazing zone was by 38, 31 and 18% greater for MF, SA and WT over the concentration of SOC within the congregation zone.

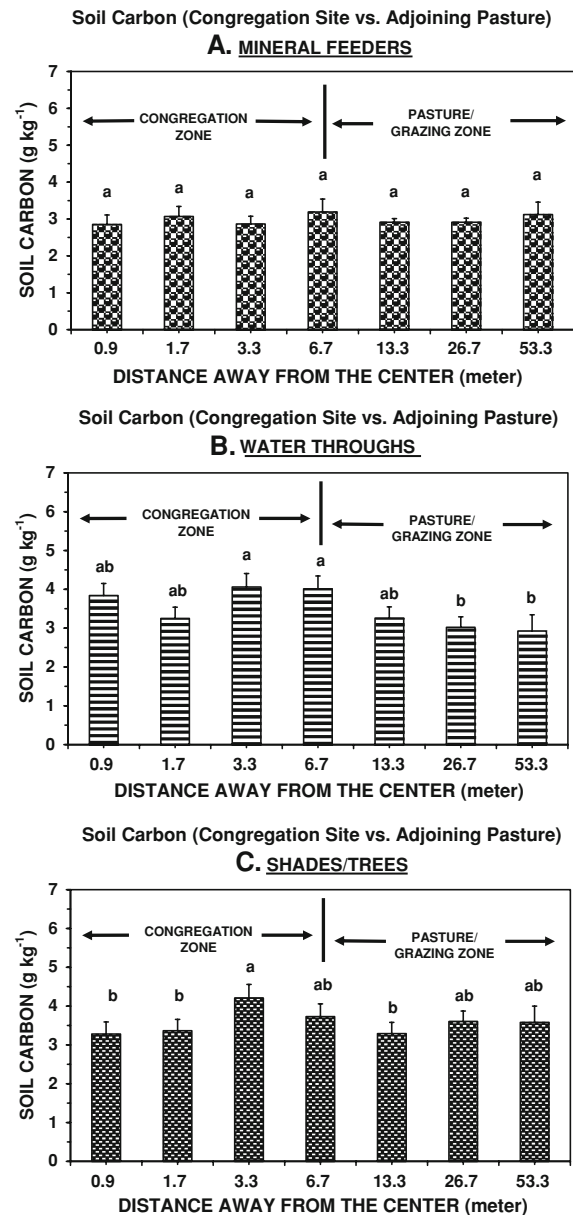
**Table 3** Analysis of variance (*F* values) on soil carbon in forage-based cow–calf congregation sites

Sources of variations	Soil carbon
Among congregation sites (CCS)	10.43***
Among sampling position (SP)	3.24**
Among year of sampling (Y)	10.13***
Distance away from the center (DC)	2.28*
Soil depth (SD)	214.38***
CCS × SD	10.12***

\*\*\**P* ≤ 0.001, \*\**P* ≤ 0.01, \**P* ≤ 0.05

Average concentrations of SOC during the summer and wet months ( $3.06 \pm 0.15 \text{ g kg}^{-1}$ ) were not significantly different from the concentrations of SOC during the fall and dry months ( $3.55 \pm 0.16 \text{ g kg}^{-1}$ ). In our study, the levels of SOC among the different congregation sites between months of high rainfall with summer temperature and months with low rainfall with cooler temperature were comparable when averaged across years, sampling positions and soil depths (Table 4).

The SA sites ( $3.58 \pm 0.08 \text{ g kg}^{-1}$ ) had higher concentrations of SOC than that at WT ( $3.47 \pm 0.11 \text{ g kg}^{-1}$ ) and MF ( $2.98 \pm 0.09 \text{ g kg}^{-1}$ ) sites (Table 5). Mean concentrations of SOC (averaged across CCS,  $n = 360$ ) from west ( $3.58 \pm 0.16 \text{ g kg}^{-1}$ ), south ( $3.38 \pm 0.13 \text{ g kg}^{-1}$ ), and north ( $3.23 \pm 0.10 \text{ g kg}^{-1}$ ) transects were comparable with each other, but significantly higher than the concentration of SOC from that of the east ( $3.09 \pm 0.11 \text{ g kg}^{-1}$ ) transect (Table 5). In this study, SOC was significantly affected by the heat sink associated with slope aspects. The least amount of SOC observed from the east aspect could be explained by higher heat sinks when compared with north or west aspect. At our location (southern latitude of the USA.), during summer months, maximum heat sinks develop in northeast facing slopes while maximum heat sinks could develop in southeast slopes during winter months. The west aspect on the other hand during summer months could have had even heat sinks while heat sinks could vary substantially during winter months. Therefore, the low amount of SOC in the east aspect could be considered a result of higher soil temperature and consequently more rapid soil moisture evaporation, less plant growth, and greater organic matter mineralization. Our results are



**Fig. 1** Comparison of SOC (mean ± SE) between congregation zone and grazing zone within mineral feeder (graph A), water troughs (graph B), and shades/trees (graph C) sites. Means of SOC are significantly different (*P* ≤ 0.05) when superscripts located at top bars are different

consistent with results in Idaho (Klemmedson 1964) and New Zealand (McIntosh et al. 2000).

Levels of SOC showed a significant (*P* ≤ 0.05) downward trend over time from 2003 to 2005. The concentrations of SOC in 2003 and in 2004 were

**Table 4** Levels of soil carbon among the different congregation sites within pastures with cow–calf operations as affected by season (wet vs. dry)

Congregation sites	Season (g kg <sup>-1</sup> )	
	Fall (dry) (n = 280)	Spring (wet) (n = 198)
Mineral feeders (MF)	3.08 ± 0.11 a	2.98 ± 0.20 a
Water troughs (WT)	3.74 ± 0.23 a	3.03 ± 0.15 a
Shaded areas (SA)	3.82 ± 0.14 a	3.18 ± 0.10 a
Mean	3.55 ± 0.16 a	3.06 ± 0.15 a

Means in row followed by same letter(s) are not significantly different from each other at  $P \leq 0.05$

similar, but their concentrations were significantly higher than the levels of SOC in 2005 (Table 5). It appeared that climatic shifts (drought) in the study area might have had influenced the levels and spatial distribution of SOC in bahiagrass-based pastures. Total annual rainfall in the area for 2004 was about 1,615 mm and 1,327 mm for 2005 or about 18% reduction of total rainfall. The effect of increasing rainfall on SOC is to promote greater plant growth and the production of larger quantities of raw materials for humus synthesis while decreasing rainfall may have more impact that is negative on soil temperature. Higher soil temperature may result

to rapid soil moisture evaporation, less plant growth and greater organic matter mineralization. Drying soil is known to cause a flush in soil C and N mineralization (Birch 1958; Powlson 1980; Elliott 1986). In general, average soil moisture within the congregation zone at the time of sampling was relatively low when compared with the average moisture content of soils within the grazing zone (Fig. 2).

The downward trend of SOC from 2004 to 2005 could also be a methodological artifact because of the changed made on how the levels of SOC were analyzed in 2005. Soils taken in 2003 and 2004 were analyzed following the dry-ash or the “loss-on-ignition” (LOI) method, while soil samples taken in the fall of 2005 were analyzed using dry combustion method. Our LOI results compare favorably with those obtained by dry combustion, so the change in our method may not have had altered the true levels of SOC in 2005. Although the SOC values between 2004 and 2005 differ significantly (statistics) from each other, their numerical difference (0.47 g kg<sup>-1</sup>) was not large (Table 5).

Concentrations of SOC varied widely ( $P \leq 0.001$ ) with soil depth, but the overall trend was consistent across the CCS (Table 5). Average levels of SOC at 0–20 cm for MF, WT and SA of  $3.52 \pm 0.11$ ,  $4.57 \pm 0.18$ , and  $4.57 \pm 0.15$  g kg<sup>-1</sup> were significantly

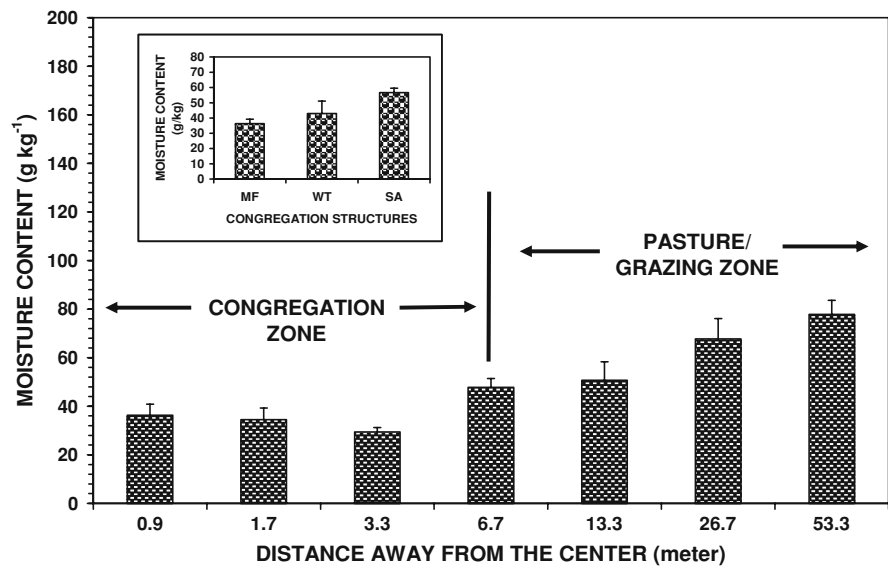
**Table 5** Levels of soil carbon among the different congregation sites within pastures with cow–calf operations as affected by sampling direction and soil sampling depth from 2003 to 2005

Landscape properties	Congregation sites (g kg <sup>-1</sup> )			
	Mineral feeders	Water troughs	Shades/trees	Mean
Sampling Position (n = 360)				
East	2.62 ± 0.09b	3.25 ± 0.22a	3.56 ± 0.21a	3.09 ± 0.11b
North	2.86 ± 0.21ab	3.44 ± 0.21a	3.50 ± 0.16a	3.23 ± 0.10ab
South	3.25 ± 0.24a	3.41 ± 0.24a	3.53 ± 0.16a	3.38 ± 0.13a
West	3.27 ± 0.25a	3.78 ± 0.32a	3.74 ± 0.25a	3.58 ± 0.16a
Time (Year) (n = 476)				
2003	3.17 ± 0.21a	3.81 ± 0.25a	3.87 ± 0.16a	3.50 ± 0.12a
2004	2.96 ± 0.11a	3.68 ± 0.21a	3.78 ± 0.08a	3.46 ± 0.11a
2005	2.78 ± 0.22a	3.03 ± 0.15b	3.18 ± 0.13b	2.99 ± 0.10b
Soil Depth (cm) (n = 690)				
0–20	3.52 ± 0.11a	4.57 ± 0.18a	4.57 ± 0.15a	4.16 ± 0.08a
20–40	2.46 ± 0.23b	2.37 ± 0.13b	2.58 ± 0.10b	2.47 ± 0.07b
Mean	2.98 ± 0.09y	3.47 ± 0.11x	3.58 ± 0.08x	

Means in column under each sub-heading followed by same letter(s) are not significantly different from each other at  $P \leq 0.05$

Means in row followed by same letter(s) are not significantly different from each other at  $P \leq 0.05$

**Fig. 2** Average moisture content (mean  $\pm$  SE) of the soil at the time of soil sampling from pastures with different congregation structures at different distances away from the center of the congregation structures



higher when compared to their concentrations at 20–40 cm of  $2.46 \pm 0.23$ ,  $2.37 \pm 0.13$ , and  $2.58 \pm 0.10$  g kg<sup>-1</sup>, respectively. Concentrations of SOC have declined by about 30, 44 and 48% for MF, SA and WT, respectively as soil depth changed from 0–20 cm to 20–40 cm (Table 5).

Results of our study did not support our hypothesis that cattle congregation sites typical on most ranches, such as MF, WT and SA, may have higher concentrations of SOC. Early results of study reported by Sigua and Coleman (2007) suggest that CCS may not be as nutrient-rich as previously thought, and therefore may not contribute more nutrients to surface and groundwater supply under Florida conditions. Intensive cattle trampling in areas around CCS, especially within the congregation zone may help to explain why SOC concentrations were not as high as we anticipated. Trampling within CCS may lead to destruction of a large portion of aerial system, stolons and roots, followed by removal of vegetation cover resulting in at least 50% bare surface (Cluzeau et al. 1992). Removal of vegetations or grass at or near the center of CCS can reduce soil fertility; soil organic matter content and SOC (Trimble and Mendel 1995).

## Summary and conclusions

Beef cattle pastures as a major part of the agro-ecological system may represent a potential sink for reducing atmospheric carbon dioxide concentrations.

The way pasture management and landscape interact to affect soil C dynamics is an issue of increasing importance to environmentalists, ranchers and public officials. The rate at which soil C is accumulating in beef pasture system is uncertain, as are the mechanisms responsible for the current C sink. Understanding cattle movement in pasture situations is critical to understanding their impact on agro-ecosystems. Movement of free-ranging cattle varies due to spatial arrangement of forage resources within pastures and the proximity of water, mineral feeders and shades to grazing sites. Results of our study did not support our hypothesis that cattle congregation sites typical on Florida ranches, such as MF, WT and SA, may have higher potential to sequester SOC.

Although not statistically significant, the average potential SOC sequestered within the grazing zone was lower than that of the congregation zone. Based on the average concentration of SOC (this study), the congregation zone of bahiagrass-based pasture may have had sequestered about  $6,840$  kg ha<sup>-1</sup> ( $684$  g m<sup>-2</sup>) of SOC while potential SOC sequestration at the grazing zone was about  $6,320$  kg ha<sup>-1</sup> or  $632$  g m<sup>-2</sup> at soil depth of 0–20 cm. Nevertheless, both the congregation zone and the grazing zone can act as carbon sinks.

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